SOLAR 1028-79/50

Solar Project Description

SIR GALAHAD COMPANY
SINGLE FAMILY RESIDENCE
Virginia Beach, Virginia
July 20, 1979

U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

NOTICE

SOLAR/1028-79/50
Distribution Category UC-59

SOLAR PROJECT DESCRIPTION
FOR
SIR GALAHAD COMPANY
SINGLE FAMILY RESIDENCE - VIRGINIA BEACH, VIRGINIA

Department of Housing and Urban Development

Under Contract Number

H-2372

David Moore
Solar Heating and Cooling Demonstration Program Manager

By

The Boeing Company
David Beers, Program Manager

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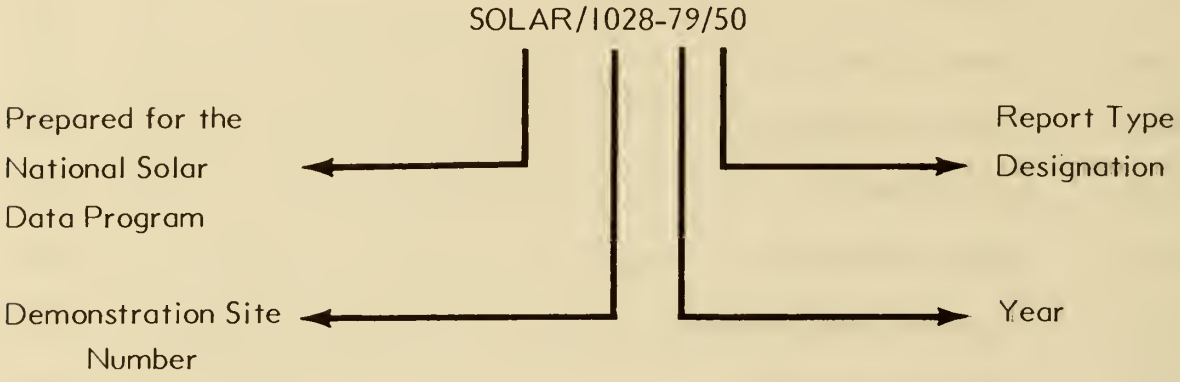
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under a specific format. For example, this report for the Sir Galahad Company solar demonstration project. Sir Galahad project site is designated as SOLAR/1028-79/50. The elements of this designation are explained in the following illustration:



Demonstration Site Number: Each project has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

Report Type Designation:
This number identifies the type of report, e.g.,

- Monthly Performance Reports -- designated by the numbers 01 (for January) through 12 (for December);
- Solar Energy System Performance Evaluations -- designated by the number 14;
- Solar Project Descriptions -- designated by the number 50;
- Solar Project Cost Reports -- designated by the number 60.

These reports are disseminated through the U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

I. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy (DOE) as mandated by the Solar Heating and Cooling Demonstration Act of 1974. The Department of Housing & Urban Development is responsible to DOE for the Solar Residential Demonstration Program. The overall goal of the Federal Demonstration Program is to assist in the establishment of a viable solar industry and to achieve a substantial reduction in fossil fuel use through widespread use of solar heating and cooling applications. An analysis and synthesis of the information gathered through this program will be disseminated in site-specific reports and summary documents as products of the National Solar Data Program. These reports will cover topics such as:

- o Solar Project Description.
- o Operational Experience.
- o System Performance Evaluation.
- o Monthly Performance Reports.

Information contained herein for this Solar Project Description report has been extracted from data collected during site visits and from reference documents such as the project proposal, designer specifications, grantee submittals, manufacturer literature, photographs, specific "as-built" data and other project documentation available. The remaining reports in this series will utilize the Solar Project Description for supporting reference.

II. EXECUTIVE SUMMARY

The following are the major solar energy descriptors:

- o Collector Type - Liquid
- o Freeze Protection - Yes, Anti-freeze, 30% Glycol - 70% Water
- o Application - Space heating, domestic hot water
- o Storage - Water, 1500 gallon tank
- o New or Retrofit - New
- o Performance Evaluation Instrumentation - Yes
- o Site-Specific Features - Heat pump and electric heat strips for auxiliary heating

The Sir Galahad Company solar energy system is installed in a single story, 1,604 square-foot, conditioned area, three bedroom single family dwelling located in Virginia Beach, Virginia. The system is designed to provide solar energy for space heating, and domestic hot water heating.

Solar energy is collected by an array of double glazed flat plate collectors with a gross area of 640 square feet. The collector array is mounted on the roof of the house and faces south at an angle of 45 degrees to the horizontal to optimize solar energy collection.

Solar energy is transferred from the collector array to a 1,500 gallon above ground storage tank. Water is used as the heat collection, transfer and storage medium. Freeze protection is provided by means of circulation of hot water from storage through the collectors. Anti-freeze additive is required.

Space heating demands are met by circulating hot water from storage through air heating coils in an air distribution system located in the house. Auxiliary space heating is provided by a heat pump and electric heater strips.

Solar energy for preheating domestic hot water is provided by circulating water from the solar storage tank through a water to water heat exchanger located solar storage tank.

The dwelling has been fully instrumented for performance evaluation since October 1978 and the data is integrated into the National Solar Data Network.

Original cost estimates for provisioning and installation of the solar system are given in section VI of this report. However, the final solar system cost and the cost of its instrumentation are not included in this report.

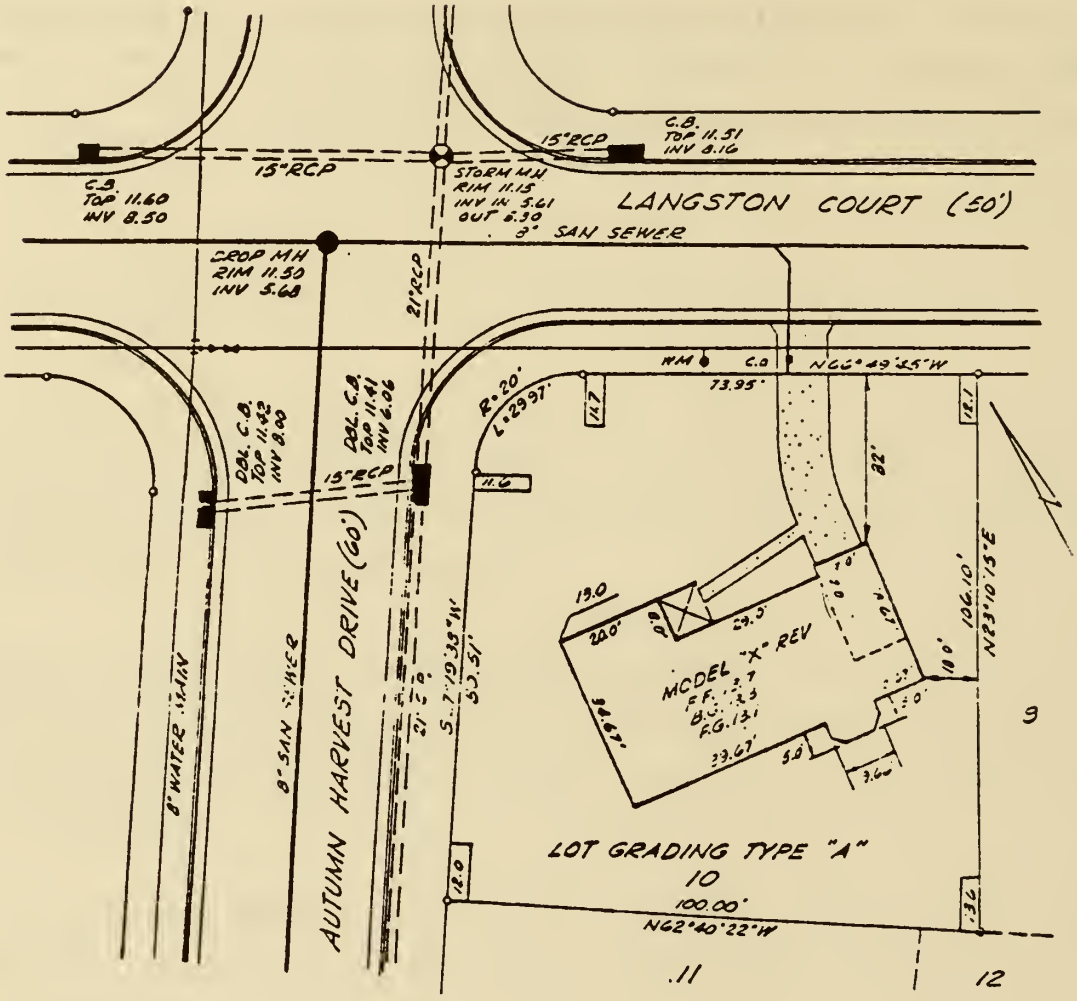


Figure III-1. Site Plan

Site Description (See Figure III-1)

- Topography - Flat
- Latitude - 37° F
- Longitude - 76° F
- Elevation - 26 feet
- Annual degree days
  - Heating - 3542
  - Data location - Norfolk, Virginia
  - Data reference - Local Climatological Data Annual Summaries, Department of Commerce, National Oceanographic and Atmospheric Administration
- Average horizontal insolation
  - January - 460 Btu/ft^2/day
  - July - 1,465 Btu/ft^2/day
  - Data location - Norfolk, Virginia
  - Data reference - U. S. Weather Bureau
- Shading
  - Heating season - None
  - Cooling season - None

Building Description

- Occupancy
  - Single family
  - Three bedroom, living/dining room, family room, kitchen tank shed, 1 3/4 bathrooms and attached garage.
- Total area - Approximately 1844 square feet
- Solar conditioned area - 1604 square feet
- Height - One story

Mechanical System

- Heating
  - Solar - Liquid active
  - Auxiliary - Heat pump with electric strips
  - Distribution - Hot air ducting
- Cooling (Non-Solar) Absorption
  - Type - Heat Pump
  - Distribution - Utilizes heating system air distribution

Domestic Hot Water

- Daily water demand - 82 gallons
- Solar - Heat exchanger in domestic water tank for preheating water by solar energy
- Auxiliary - Electric hot water

IV. SOLAR SYSTEM DESCRIPTION

A. General Overview

This residential solar demonstration project (Sir Galahad Company Grant H-2470) located at Virginia Beach, Virginia is a liquid active system utilized for heating, and domestic hot water. A heat pump is provided for supplementing space heating.

Subsequent sections describe the collector, storage, energy-to-load, and auxiliary subsystem. Specific details of the operating modes and controls are described in the final section. Figure IV-A-1 is a system schematic diagram.

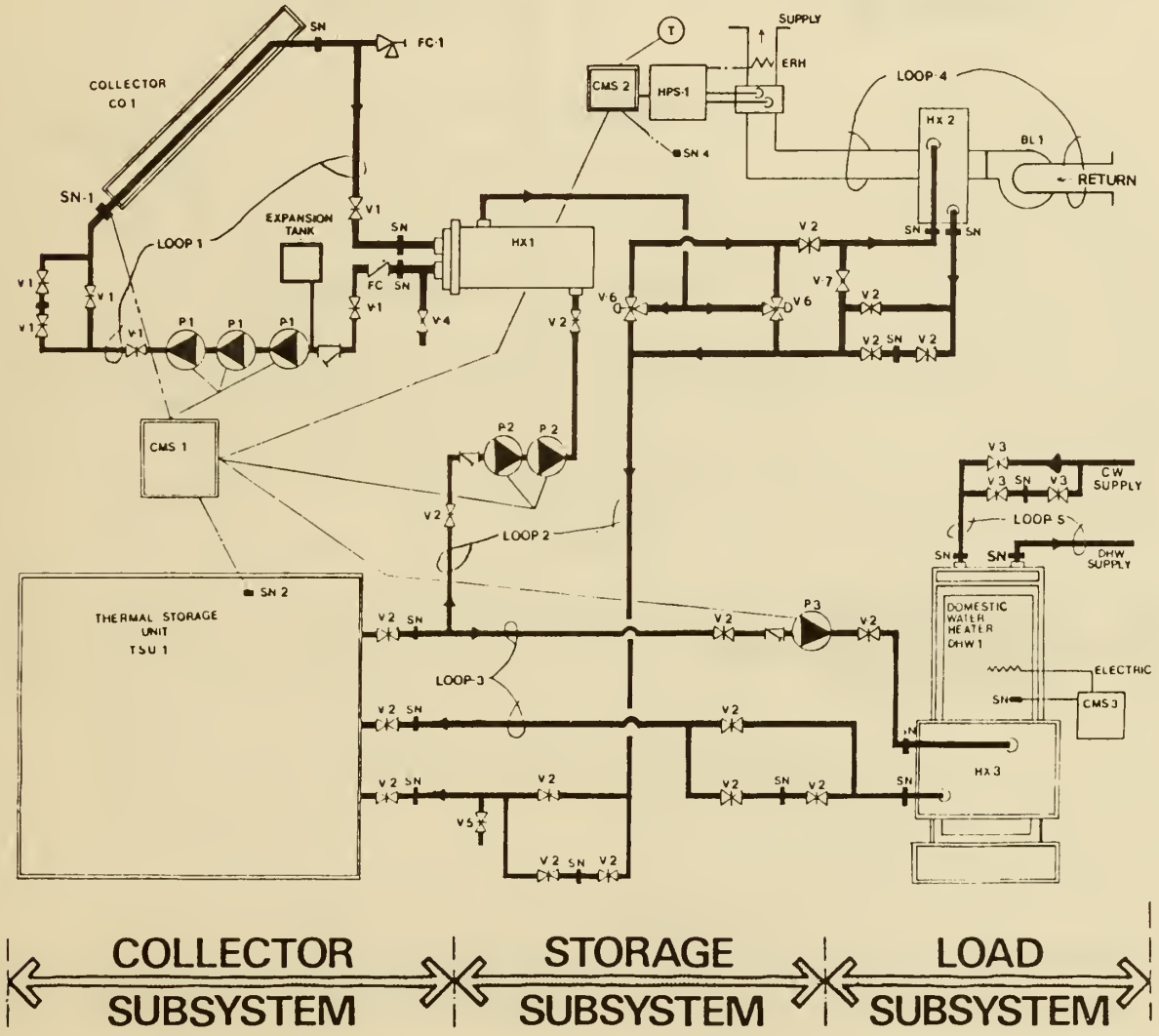


Figure IV-A-1. General Overview

B. Collector Subsystem (See Figure IV-B-1)

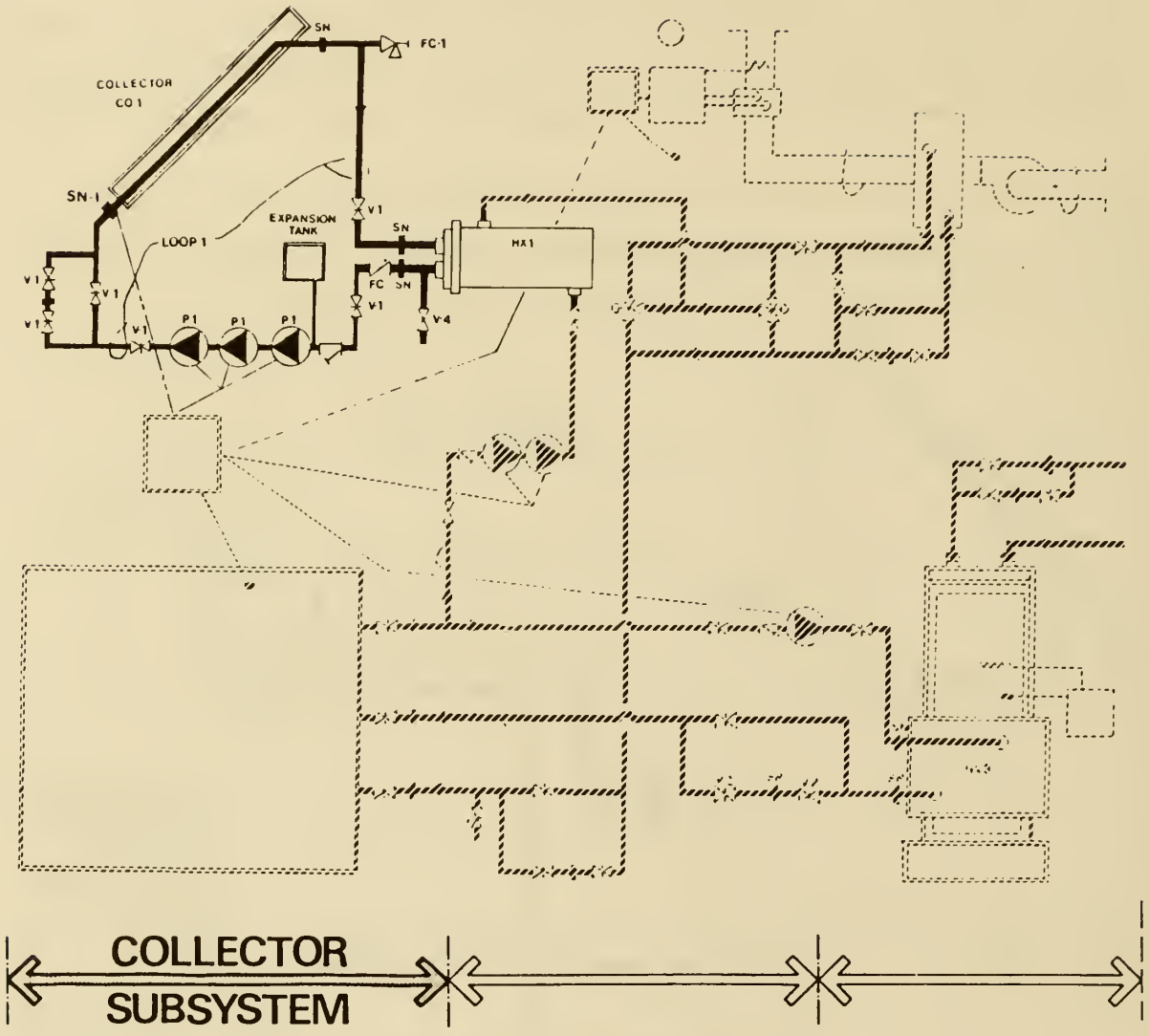


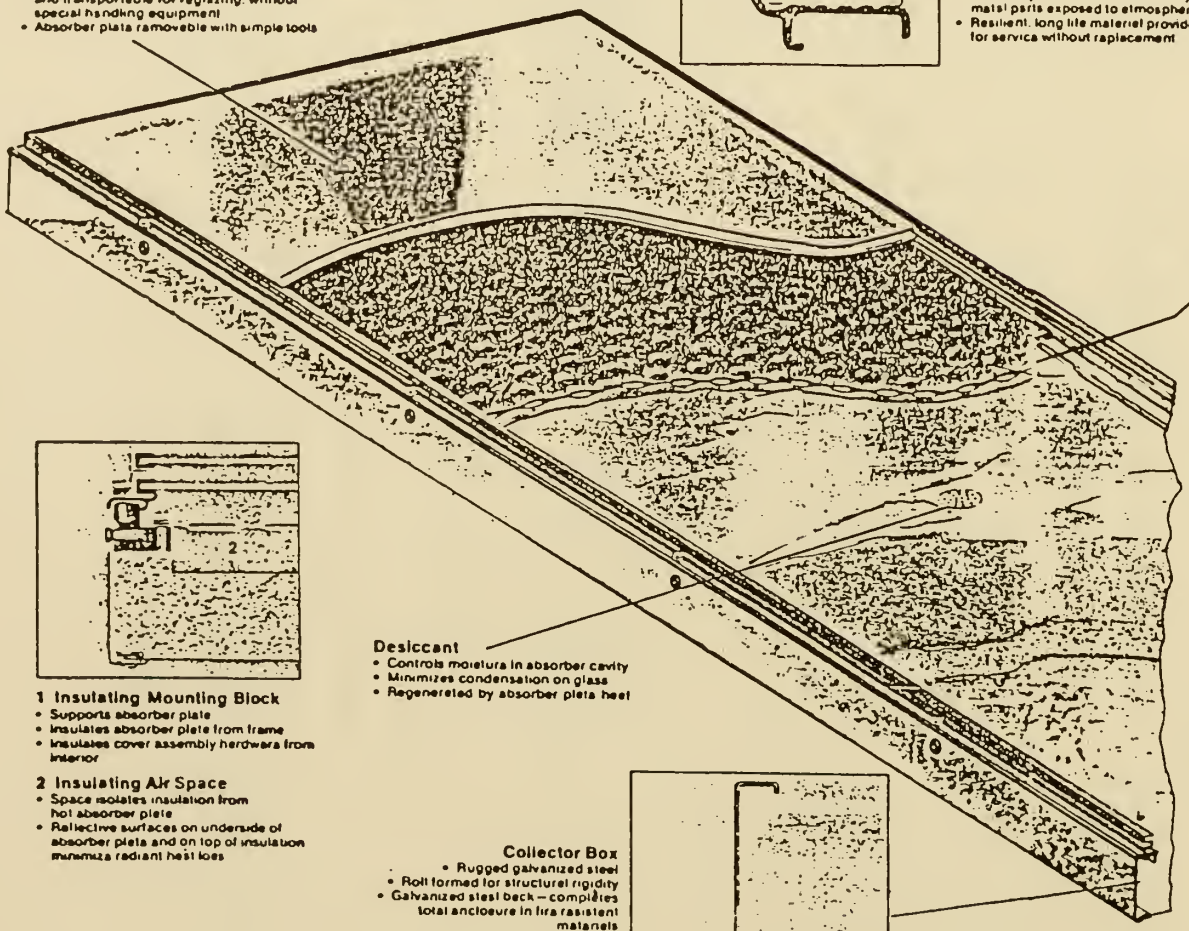
Figure IV-B-1. Collector Subsystem

Collector array system consists of 40 single glazed selective surface, flat plate collector panels. Freeze protection is provided by a 30% ethylene-glycol water mixture in the collector and a heat exchanger is external to the storage tank.

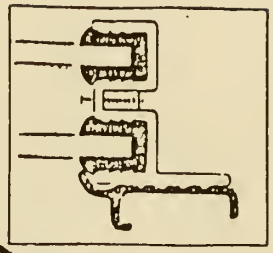
Collector (COL-1) (See Figure IV-B-2)

- Manufacturer - Revere
- Model name/number - Sun Roof
- Type - Liquid flat plate, tube, and plate
- Location - Roof
- Orientation - Fixed, South
- Tilt angle - 45^{o} from horizontal
- Number of collector panels - 40
- Array configuration - Two rows of 20 panels
- Collector
  - Total gross area of array - 640 sq. ft.
  - Net aperture area - 584 sq. ft.
  - Weight per panel, empty - 100 lbs
  - Weight per panel, full - 103 lbs
  - Weight of filled array and support structure - 4520 lbs.
  - Panel length - 96.0 inches
  - Panel width - 24.0 inches
  - Frame depth - 2.5 inches
  - Standoff height - 0 inches
- Glazing (cover plate)
  - Number of cover plates - One
- Cover plate
  - Manufacturer - Varies
  - Material - Low iron tempered glass
  - Thickness -0.125 inch
  - Coating - None

Chamberlain Solar Collector Panel Specifications

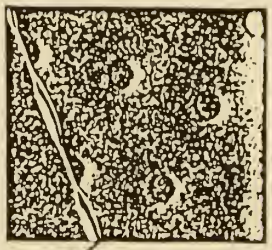


Serviceable in the Field
- All service can be provided from the top
- Glass cover frame is easily removable and transportable for reglazing, without special handling equipment
- Absorber plate removable with simple tools



Cover Assembly
- Rigid extruded aluminum frame
- Marine glazing
- Single, long life, weather resistant glass
- Low iron glass – high transmissivity
- Minimum restriction for insolation entry
- Tempered surface glass provides resistance to breakage

Cover Gasket
- Provides seal between cover and box
- Thermally isolates absorber cavity from metal parts exposed to atmosphere
- Resilient, long life material provides for service without replacement



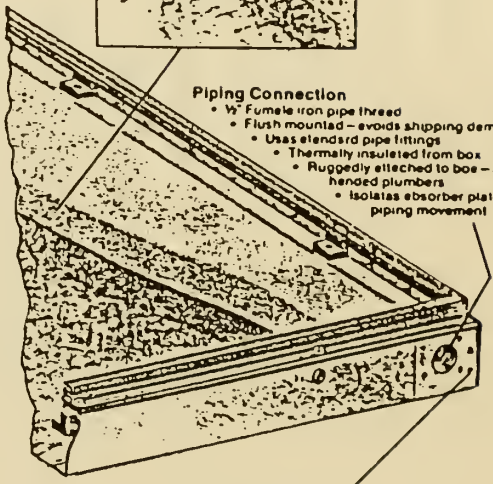
Absorber Plate
- Maximum wetted surface
- Minimum flow resistance
- Rugged metal construction
- Pressure tested
- Selection of coatings available

Insulation
- Maximum insulation with minimum volume of insulation
- Reflective upper surface to minimize temperature of insulation

1 Insulating Mounting Block
- Supports absorber plate
- Insulates absorber plate from frame
- Insulates cover assembly hardware from interior

2 Insulating Air Space
- Space isolates insulation from hot absorber plate
- Reflective surfaces on underside of absorber plate and on top of insulation minimize radiant heat loss

Desiccant
- Controls moisture in absorber cavity
- Minimizes condensation on glass
- Regenerated by absorber plate heat



Piping Connection
- ½" Female iron pipe thread
- Flush mounted – avoids shipping damage
- Uses standard pipe fittings
- Thermally insulated from box
- Ruggedly attached to box – allows for heavy handed plumbers
- Isolates absorber plate from external piping movement

Collector Box
- Rugged galvanized steel
- Roll formed for structural rigidity
- Galvanized steel back – completes total enclosure in fire resistant materials

Mounting
- 2 – 5/16" weld nuts
- Rigid
- Easy to adapt to any support
- No projections – will not become damaged in shipment

Figure IV-B-2. Solar Collector

- Optical properties (solar region) (infrared region)
  - Transmittance 91% 91%
  - Reflectance 6% 6%
  - Emittance - 93%
- Edge or surface treatment, other than coating - Mechanically ground
- Coating on cover plate material - None

- Absorber
  - Manufacturer - Revere
  - Model - Sun Roof
  - Material - Copper, laminated to plywood
  - Substrate material dimension
    - Thickness - 0.010 inch
    - Length - 96.0 inches
    - Width - 24.0 inches
- Coating
  - Manufacturer - 3 M
  - Model Name/Number - Nextel Black Velvet
  - Application method - Paint, sprayed
  - Absorptance - 96% solar region; 95% infrared
  - Reflectance - 4% solar region; 5% infrared
  - Emittance - 96%
- Heat transfer fluid passages
  - Location - On absorber
  - Pattern - Parallel
  - Materials - Copper
  - Wall thickness - 0.032 inch
  - Internal diameter - 0.595 inch

- Maximum operating conditions
  - Temperature - 296° F
  - Pressure - 65 psi
- Fluid passage bond to substrate - Copper flake adhesive
- Protective coating inside fluid passage - None

- Insulation
  - Layer one - sides
    - Manufacturer - Varies
    - Product Name/Number - Fiberglass
    - Material - Rigid urethene
    - Thermal resistance - R-19
  - Layer one - back
    - Manufacturer - Varies
    - Product Name/Number - Fiberglass
    - Material - Glass fiber
    - Thermal resistance - R-19

- Gaskets and sealants
  - Inner cover - Dura Ribbon
  - Outer cover - Dura Ribbon
  - Backing plate - Dura Ribbon
  - Penetrations - Dura Ribbon
- Frame
  - Manufacturer - Roof of the residence

- Desiccant - None
- Freeze protection - Antifreeze
- Overheating protection - Relief valve
- Passive collector heat transfer control - None

- Collector performance
  - Method of evaluation - ASHRAE $(t_i-t_a)/I_t$
  - y intercept - 0.68° F ft^2hr/Btu
  - Slope - $(F_R U_L)$ 1.13

Point Number	1	2	3	4
n = Collector thermal efficiency (%) -	57.8	46.7	34.6	22.2
t_i = collector inlet temperature (°F) -	110	134	170	200
t_a = ambient air temperature (°F) -	77	74	71	65
I_t = insolation intensity Btu/hr ft^2 -	349	318	335	333
ASHRAE $(t_i-t_a)/I_t$ -	0.09	0.19	0.30	0.41

  - Test flow rate - 60.0 lb/hr
  - Test collector area
    - Gross - 16.0 sq.ft.
    - Net - 14.6 sq.ft.
  - Fluid specific heat - 1.00 Btu/lb° F
  - Test fluid medium - Water

Liquid Circulation Loop No. 1 (COL-1 to HX-1)

- Design maximum operating temperature - 180° F
- Heating design liquid flow - 15 gpm
- Cooling design liquid flow -
- Provision for expansion - Yes, expansion tank
- Heat transfer medium - Water
  - Specific heat - 0.98 Btu/lb/° F
  - Density - 61 lb/ft^3
  - Boiling point - 212° F
  - Freezing point - 32°
  - Maximum recommended use temperature - 220° F
  - Toxicity - Non-potable
  - pH factor -
  - Chemical feeder to maintain pH factor - No
  - Inhibitor - No
- Loop Description - Collector to Storage
- Piping
  - Rigid - Copper, type M
  - Piping insulation - Cellular rubber
  - Location - Above grade
  - Filters - Y strainer

C. Storage Subsystem (See Figure IV-C-1)

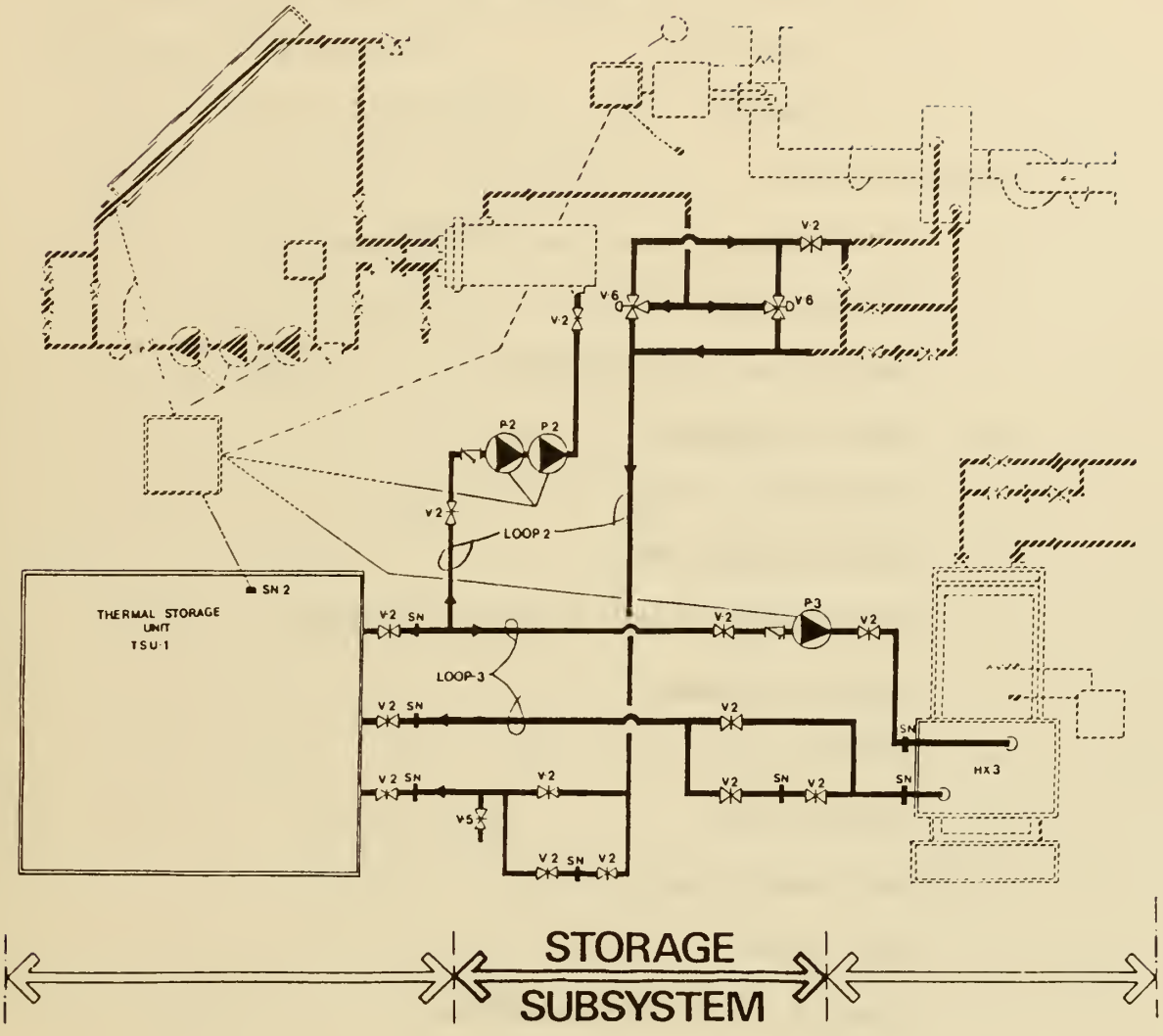


Figure IV-C-1. Storage Subsystem

Solar energy storage is provided by a 1,500 gallon underground storage tank. This tank is made of steel and measures 5 feet in diameter, 9'0" in length and is covered with vapor barrier over fiberglass insulation. Water is heated by HX-1 and circulated by pump, P-2, to storage tank (TSU-1) and to the building heating unit (HX-2) which is located in the air distribution system.

Thermal Storage Unit (TSU-1)

- Container
  - Total storage volume - 200 cu. ft. (1500 gal)
    - Length - 9.0'
    - Diameter - 5.3'
- Storage medium
  - Heating design temperature - 190° F maximum
  - Medium - Water (100%)
  - Specific heat - 1.00 Btu/lb/° F
  - Density - 62 lb/ft^3
  - Boiling point - 212° F
  - Freezing point - 32° F
  - Recommended medium temperature - 190° F
  - Toxicity - Potable
  - pH Factor - 7.0
  - Inhibitor - No
- Container construction
  - Type - Steel
  - Location - Shed adjoining building
  - Auxiliary heaters - No
  - Insulation - Glass, fiber
  - Exterior finish - Foil
  - Filters - Strainer at each pump
  - Thermal Resistance - R-11

Liquid Circulation Loop No. 2 (TSU-1 to HX-1)

- Design operating temperature - 180° F
- Heating design liquid flow - 15 gpm
- Heat transfer medium
  - Medium - 100% Water
  - Specific heat - 1.00 Btu/lb°F
  - Density - 62 lb/ft^3
  - Boiling point - 212° F
  - Freezing point - 32° F
  - Maximum recommended use temperature - 190° F
  - Toxicity - Potable
  - pH factor -
  - Chemical feeder - No
  - Inhibitor - No
  - Piping
    - Rigid - Copper
    - Insulation - Cellular rubber
    - Location - Above grade
- Circulator pump (P-2), TSU-1-to-HX-1
  - Manufacturer - Grundfos
  - Model Name/Number - UP 2664
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure -
    - Temperature - 230° F

- Material exposed to heat transfer fluid - Copper
- Motor size - 0.08 bhp, 115 V, single phase, 60 Hz
- Maximum motor speed -
- Drive - Direct
- Speed Single
- Pump speed -
- Circulating volume - Low head mode - 31 gpm
- Operating head (dynamic) - Low head mode - 9 psi
- Motor operation -

- Distribution Valve (V-2)
  - Function - Drain
  - Operation - Manual
  - Type - Globe
  - Materials exposed to heat transfer fluid -

Control Mode Selector (CMS-1)

- Modes controlled
  - Collector to storage - ON -
  - Storage to space - ON - below 110° F
  - Storage to space - OFF - above 110° F
  - HX-1 (Collector heated HX-1)
    - ON - +20° F
    - OFF - +20° F
  - Sensors (SN-02 and (SN-03)

Liquid Circulation Loop No. 2 (HX-1 to HX-2)

- Design maximum operation temperature - 180° F
- Heating design liquid flow - 15 gpm
- Heat transfer medium
  - Medium - 100% Water
  - Specific heat - 1.00 Btu/lb/° F
  - Boiling point - 212° F
  - Freezing point - 32° F
  - Maximum recommended use temperature - 190° F
  - Toxicity - Potable
  - pH factor - 7.0
  - Chemical feeder to maintain pH factor - None
  - Inhibitor - No
- Piping
  - Rigid - Copper, type M
  - Insulation - Cellular rubber
  - Location - Above grade
  - Filters - Y strainers

Liquid Circulation Loop No. 3 (TSU-1 to HX-3, DHW)

- Design maximum operation temperature - 180° F
- Heating design liquid flow - 2 gpm
- Heat transfer medium
  - Medium - 100% Water
  - Density - 62 lb/ft^3
  - Specific heat - 1.00Btu/lb/°F

- Boiling point - 212° F
- Freezing point - 32° F
- Maximum recommended use temperature - 190° F
- Toxicity - Potable
- pH factor - 7.0
- Chemical feeder to maintain pH factor - None
- Inhibitor - None

- Piping
  - Rigid - Copper, type M
  - Insulation - Cellular foam
  - Location - Above grade
  - Filters - None
- Circulator pump (P-3), TSU-1-to-HX-3
  - Manufacturer - Grundfos
  - Model Name/Number - UPS 2042
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure -
    - Temperature - 230° F
  - Material exposed to heat transfer fluid - Copper
  - Circulating volume - Low head mode - 24 gpm
  - Operating head (dynamic) - Low head mode - 6 psi
  - Motor operation - 0.5 bhp
- Heat Exchanger (HX-3)
  - Manufacturer - Manufacturer on site
  - Type of exchanger - Liquid to liquid
  - Type of flow - Cross

- Heat exchanger design - Tube around tank
- Number of separations - Double
- Convection
  - Side one - Forced
  - Side two - Natural
- Circulation loop
  - Side one - 3
  - Side two - 5
- Piping - Copper, type M
- Flow rate
  - Side one - 2 gpm
  - Side two - 80 gal/day
- Related pump - P-3

- Distribution Valve (V-2)and (V-7)
  - Function - ON-OFF
  - Operation - Manual
  - Type - Gate
- Distribution Valve (V-6)
  - Manufacturer -
  - Model Name/Number -
  - Function - Flow switching
  - Operation - Automatic
  - Type - 3-way diverting

Air Circulation Loop No. 4 (HX-2 to Space Heating)

- Location - Above grade

- Blower - (BL-1) squirrel cage fan, centrifugal
- Heat Exchanger (HX-2)
  - Type of flow - Cross
  - Heat exchanger design - Fin coil
  - Type of exchanger - Air-to-liquid
  - Convection
    - Air side - Forced
    - Liquid side - Forced
    - Effectiveness -
    - Material - Copper
  - Part of circulation loop (s) - 2 and 4
  - Design flow quantity
    - Air side - 12 to 1500 cfm
    - Liquid side - 15 gpm
  - Temperature
    - Air side - Less than 68^{o} F DB
    - Liquid side - Above 110^{o} F DB
- Control Mode Selector (CMS-2)
  - Auxiliary to space
    - ON - Less than 66^{o} F (SN-03)
    - OFF - Greater than 68^{o} F (SN-03)
  - ERH Assist to HPS-1
    - ON - Less than 36^{o} F (SN-04)
    - OFF - Greater than 36^{o} F (SN-04
- Sensor
  - Type - Thermostat

Circulation Loop No. 5 (DHW-1 to Supply)

- Flow rate - 80 gal per day
- Heat transfer medium
  - Medium - 100% water
  - Specific heat - 1.00 Btu/lb/^{o}F
  - Density - 62 lb/ft^{3}
  - Boiling point - 212^{o} F
  - Freezing point - 32^{o} F
  - Maximum recommended use temperature - 190^{o} F
  - Toxicity - Potable
  - pH factor -
  - Chemical feeder - No
  - Inhibitor - No
- Piping
  - Rigid -
  - Insulation -
  - Location -
- Distribution Valve (V-3)
  - Function - ON-OFF
  - Operation - Manual
  - Type - Gate
  - Materials exposed to heat transfer fluid -

E. Energy to Load Subsystem (See Figure IV-D-1)

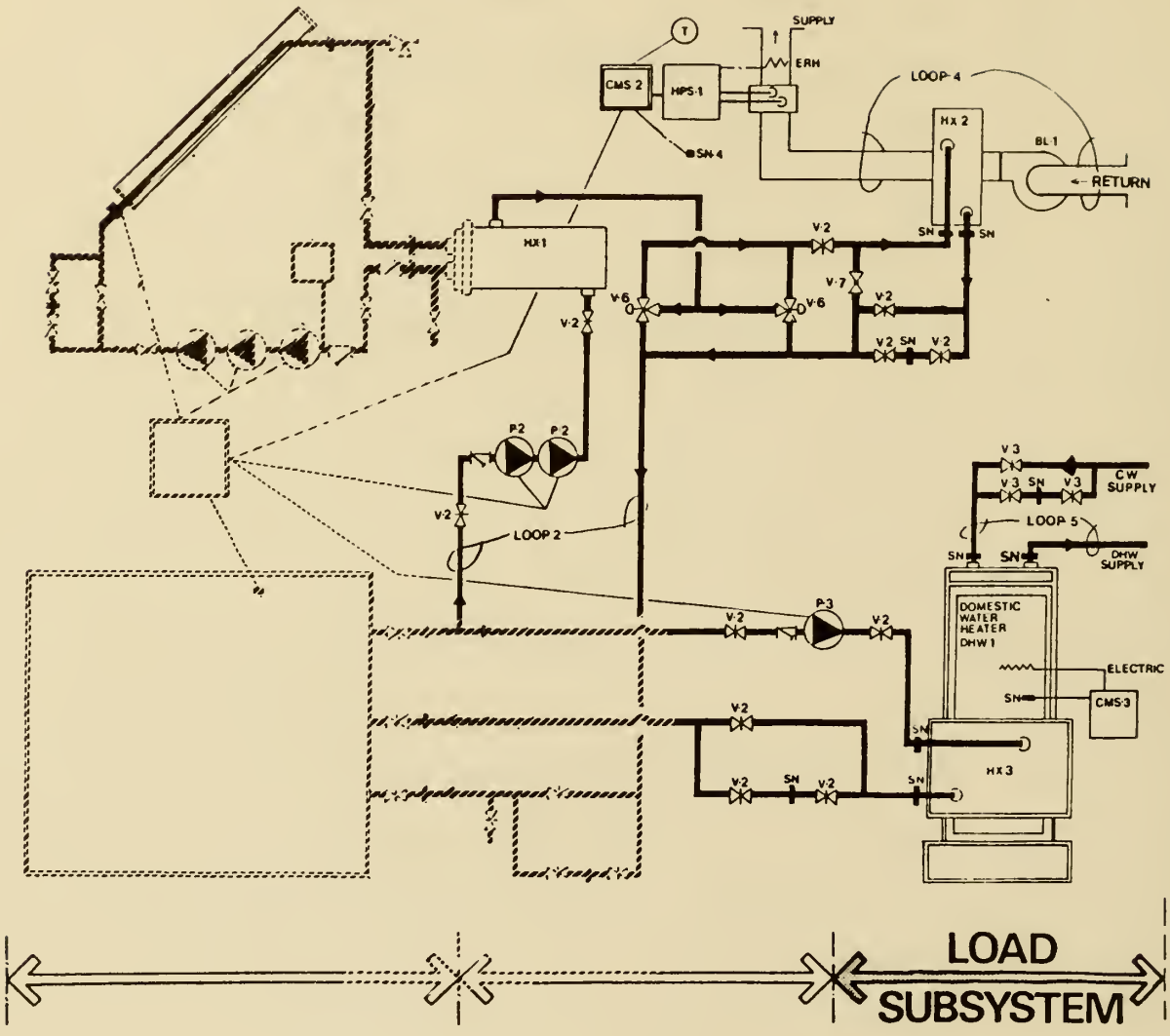


Figure IV-D-1. Energy-to-Load Subsystem

Solar energy stored in the 1500 gallon storage tank is used to meet the space heating demands by circulating it through heating coils in the air distribution system. Auxiliary space heating is provided by a heat pump (HPS-1) with supplemental electric strips.

- Circulator pump (P-1)
  - Manufacturer - Grundfos
  - Model Name/Number - UP 2664
  - Type - Centrifugal
  - Maximum operating conditions
    - Dynamic pressure -
    - Temperature - 230° F
  - Material exposed to heat transfer fluid - Steel body, stainless steel impeller and copper piping
  - Motor size -
  - Maximum motor speed -
  - Drive -
  - Speed -
  - Pump speed -
  - Circulating volume - Low head mode - 31 gpm
  - Operating head (dynamic) - Low head mode - 9 psi
  - Motor operation - 0.08 bhp
- Heat exchanger (HX-1)
  - Manufacturer - Bell & Gossett
  - Model Name/Number - STH 630-4
  - Type - Liquid-to-liquid
  - Number of fans -
  - Type of flow - Counter
  - Design - 4 pass tube, 4 pass shell
    - Separation - Single
    - External exposed surface area - 40.8 sq. ft.
    - Convection - Forced

- Maximum manufactureres rated

	Side One	Side Two
- Temperature -	300°F	300° F
- Pressure -	150 psi	225 psi

  - Material - Copper, steel, cast iron body, brass tube hubs
  - Capacity - 15 gpm
- Distribution Valve (V-1)
  - Manufacturer
  - Function - Anit-freeze loop 1
  - Operation - ON-OFF, Manual
  - Type - Gate
  - Material exposed to heat transfer fluid -
- Distribution Valve (V-4)
  - Manufacturer -
  - Model Name/Number -
  - Function - Drain (Anti-freeze Loop 1) ON-OFF
  - Operation - Manual
  - Type - Globe
  - Materials exposed to heat transfer fluid -

Control Mode Selector (CMS-1)

- Modes controlled
  - Collector to storage - Yes
  - Storage to space - Yes
  - Storage to hot water - Yes
- Sensors (SN-1) and (SN-2)
  - Manufacturer -
  - Type - Temperature, Thermister

- Fail Safe Control (FC-1)
  - Manufacturer -
  - Product Name/Number -
  - Type - Pressure relief valve
- Flow Control (FC-2)
  - Manufacturer -
  - Type - Check valve

E. Auxiliary Subsystems (See Figure IV-E-1)

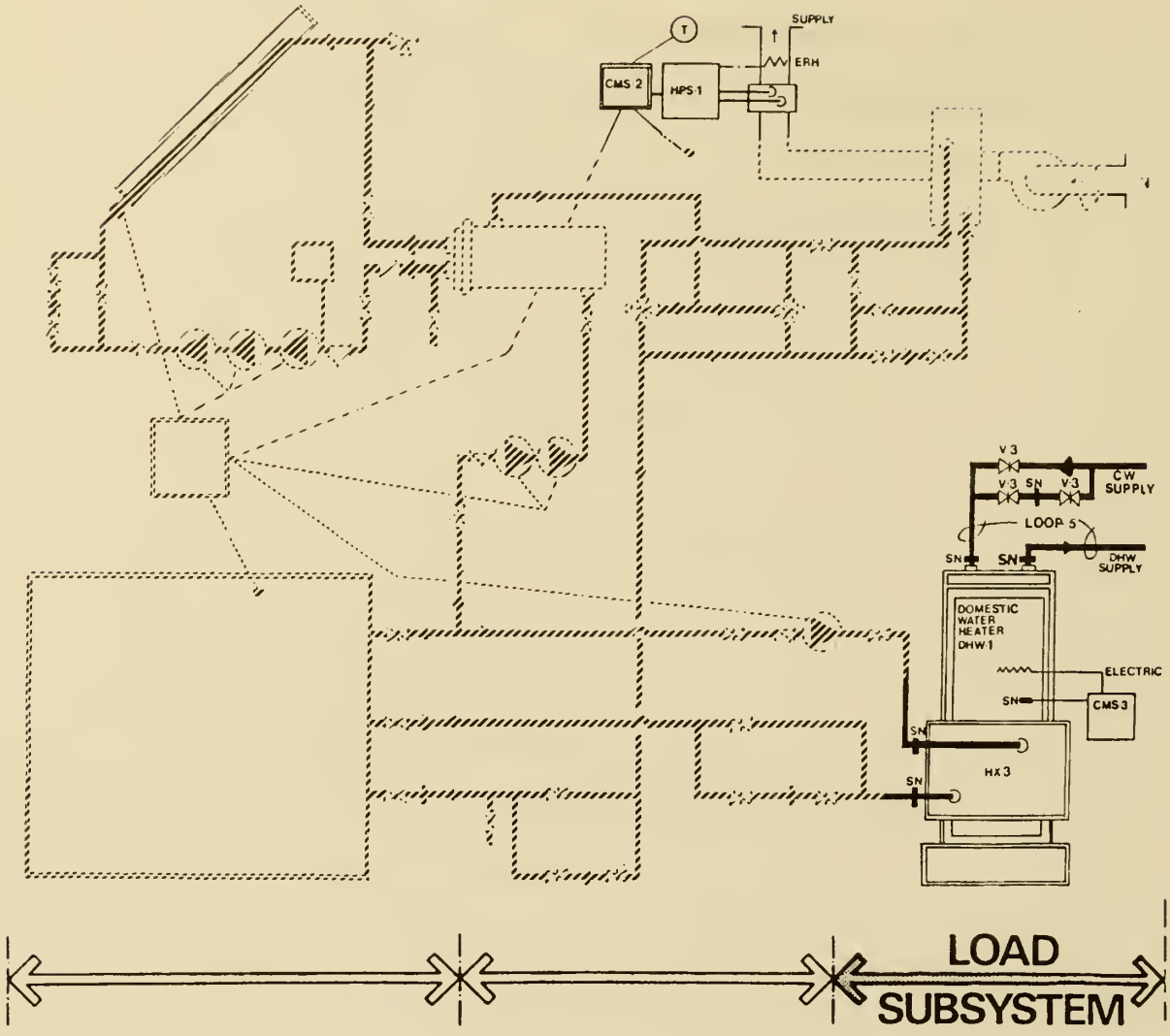


Figure IV-E-1. Auxiliary-to-Load Subsystem

The auxiliary subsystems, domestic hot water tank, heat pump (HPS-1) and Blower (BL-1) mentioned in the foregoing Energy to Load Subsystem have been grouped in this section for descriptive purposes, their function and purpose have been previously described.

Auxiliary Loads (DHW-1. BL-1, and HPS-1)

- Domestic Water Heater (DWH-1) includes HX-3
  - Manufacturer - Ruud
  - Model - Solar Servant 6 Kw
  - Energy source - Electric
  - Tank size - 82 gal
  - Energy input - 20,000 Btu/hr
  - Energy output - 20,000 Btu/hr
  - Maximum pressure rating -
  - Maximum temperature rating -
  - Design operating pressure -
  - Heating stages -
  - Maximum recovery rate - 50 gal per hr
  - Yearly average inlet temperature - 50^{o} F
  - Design output temperature - 140^{o} F
  - Thermal resistance - R-10
  - Standby heat loss -
  - Corrosion protection anodes -
  - Burner ignition method -
  - Flue vent -
- Control Mode Selector (CMS-3)
  - Modes controlled - Auxiliary hot water heater
  - Sensor - (SN-05)
    - Type - Thermostat
- Heat Pump (HPS-1)
  - Manufacturer - Carrier
  - Model Name/Number - 33BQ003 (outdoor compression) 40GQ004 (heat pump)

- Type - Split system, direct expansion
- Refrigeration fluid - Freon
- Power source - Electric
- Manufacturer's rating - Input 4778 Btu/hr, Output 15,017 Btu/hr
- Demand side, Circulation Loop - Described under loop 4
- Distribution - Blower (BL-1)
  - Motor size - 1/3 hp, 115 v, single phase, 60 Hz
  - Speed - 3 speed (850, 950, 1050 rpm)

- Control Mode Selector (CMS2) - Refer to Loop 4
  - Modes controlled - Auxiliary heating

F. Modes of Operation (See Figure IV-F-1)

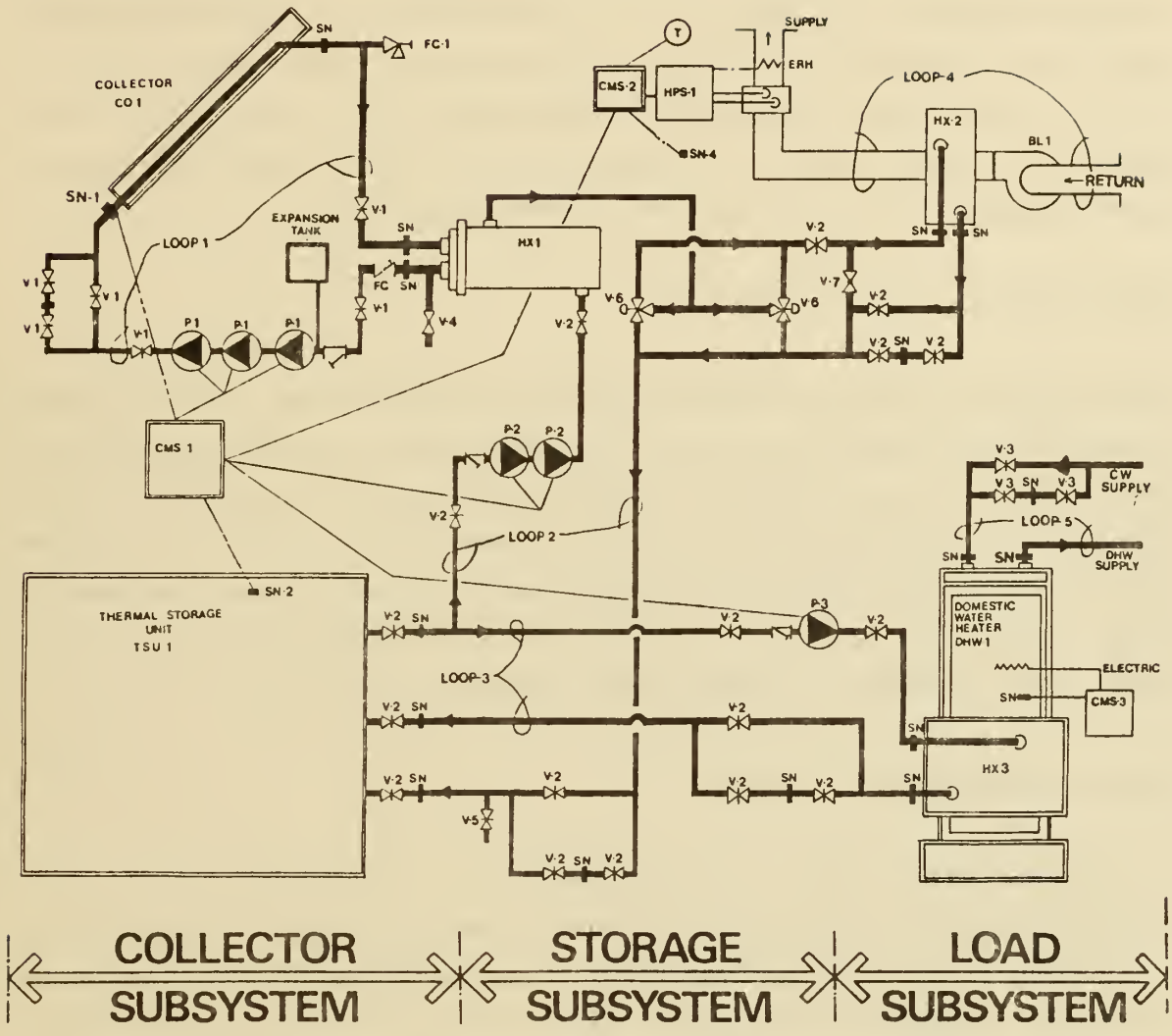


Figure IV-F-1. Controls Diagram

The Sir Galahad Company's solar system is shown on Figure IV-F-1. The system consists of the following four subsystems: a) Collector, b) storage, c) load (space heating and d) auxiliary loads subsystem. Operation of the solar system and auxiliary subsystems may involve one or more of the five modes of operations described below.

Mode 1 - Collector-to-Storage:

When the collector temperature control sensor, located in the collector outlet manifold, indicates a temperature 17° F greater than the storage temperature control sensor, located at the bottom of the storage tank, collector pumps (P-1 and P-2) are activated and will circulate water through the storage tank and the collectors. Collector pump (P-2) continues to run until the collector temperature becomes less than 3° F greater than the storage temperature.

Mode 2 Space Heating-from-Storage:

Solar energy from storage is used for space heating when there is a demand from the space heating thermostat and there is sufficient thermal energy in storage, as indicated by the storage tank top temperature, being greater than 90° F. In this mode space heating pump (HPS-1) and the Blower (BL-1) in the air distribution system are activated. Valves V-6 and V-2 are positioned to allow flow from the storage tank through the heating coils of the heat exchanger and back to the storage tank. The electric auxiliary heater is disabled in this mode.

Mode 3 - Auxiliary-Space Heating:

The auxiliary heating mode is used when there is a demand for space heating from the space thermostat and there is not sufficient thermal energy in storage to meet the demand. In this mode heat pump (HPS-1) and the blower (BL-1) are activated, allowing flow through the heating coils, and the Electric heating strips are enabled to provide the required thermal energy, when outdoor temperature is below 36° F.

Mode 4 - Domestic Hot Water Heating:

Energy from storage is used to heat domestic hot water when the temperature in the DHW heater is below 140° F and is also 15° F less than the storage tank top temperature. When both of these conditions are met, pump P-3 is activated, circulating water from the DHW heater through a heat exchanger (HX-3) located in the storage tank. Auxiliary electric DHW heating occurs if the temperature of the hot water in the tank drops below 130° F.

Mode 5 - Auxiliary Domestic Hot Water Heating:

This mode is activated directly by DHW-1 tank thermostat when the solar energy source is not able to maintain water temperature at 140° F or desired setting.

V. PERFORMANCE EVALUATION INSTRUMENTATION

A. The National Solar Data Network

The National Solar Data Network (see figure V-A-1) has been developed for the Department of Energy to process data collected from specific residential demonstration sites which were selected for thermal performance evaluation. The data flow in the Network includes monthly and seasonal system performance reports describing the thermal performance of the solar energy system and subsystems.

The performance evaluation instrumentation at each selected demonstration site is part of a comprehensive data collection system that allows for valid analyses of the solar system performance. Collected data are both applicable and practical in calculating thermal performance factors that describe the behavior of the solar system (see NBSIR 76-1137), National Bureau of Standards. Additional instrumentation may also be included as a result of site-specific requirements. Typically, the instrumentation includes sensors that monitor the following:

- Total insolation in the plane of the collector array
- Ambient temperature
- Collector subsystem flow rate and temperatures
- Storage inlet flow rate and temperatures
- Storage outlet flow rate and temperatures
- Storage temperature
- Storage-to-load subsystem flow rate and temperatures
- Auxiliary fuel flow rates

Site data are recorded sutomatically at prescribed intervals by the Site Data Acquisition System (SDAS). The recorded data are transmitted daily to the Communications Processor in the Central Data Processing System (CDPS). The communications link between every SDAS and the CDPS consists of voice-grade telephone lines and telephone data couplers. A reading is transmitted from the SDAS internal timer with every data sample to ensure that the data are time-tagged correctly.

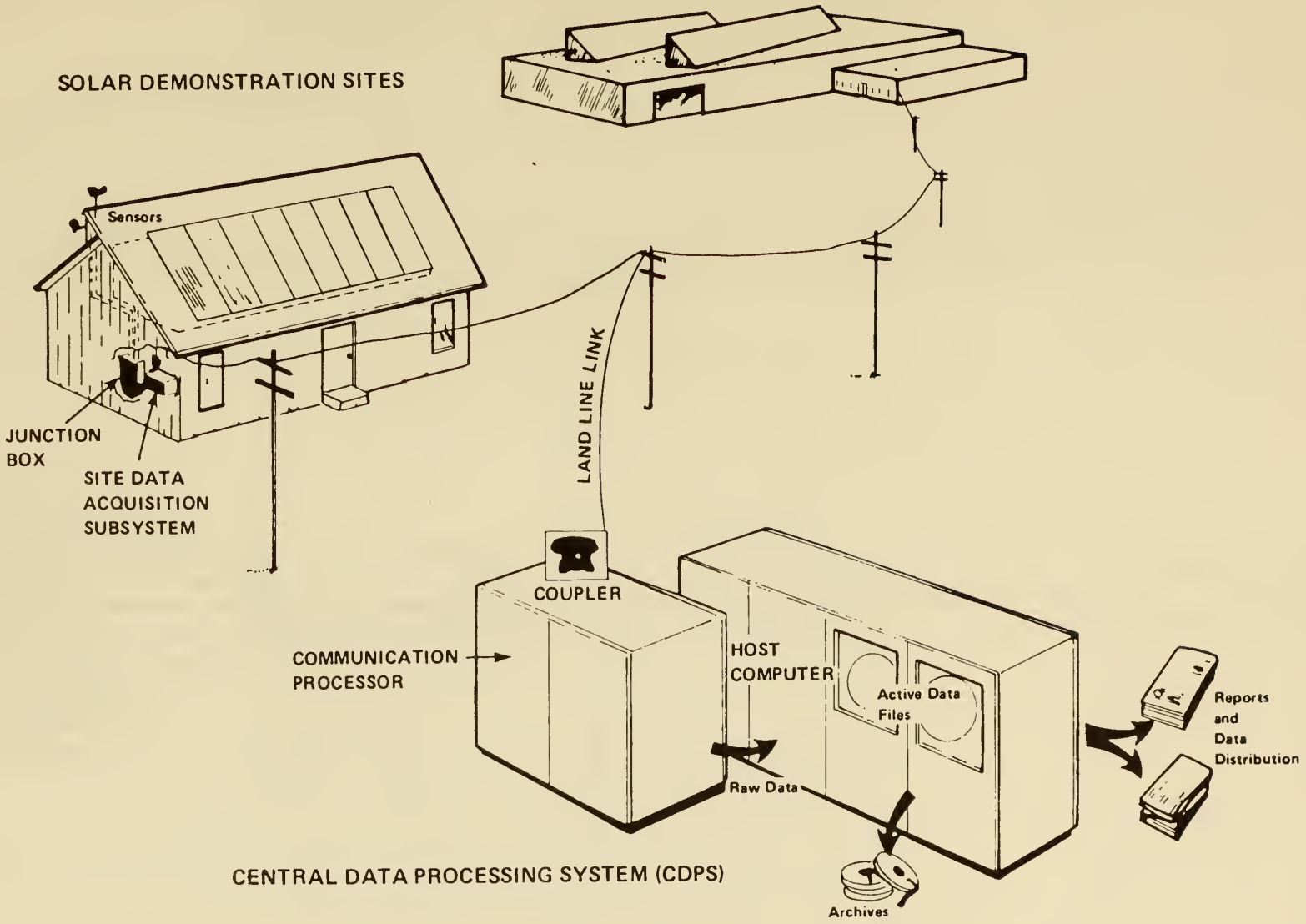


Figure V-A-1. The National Solar Data Network

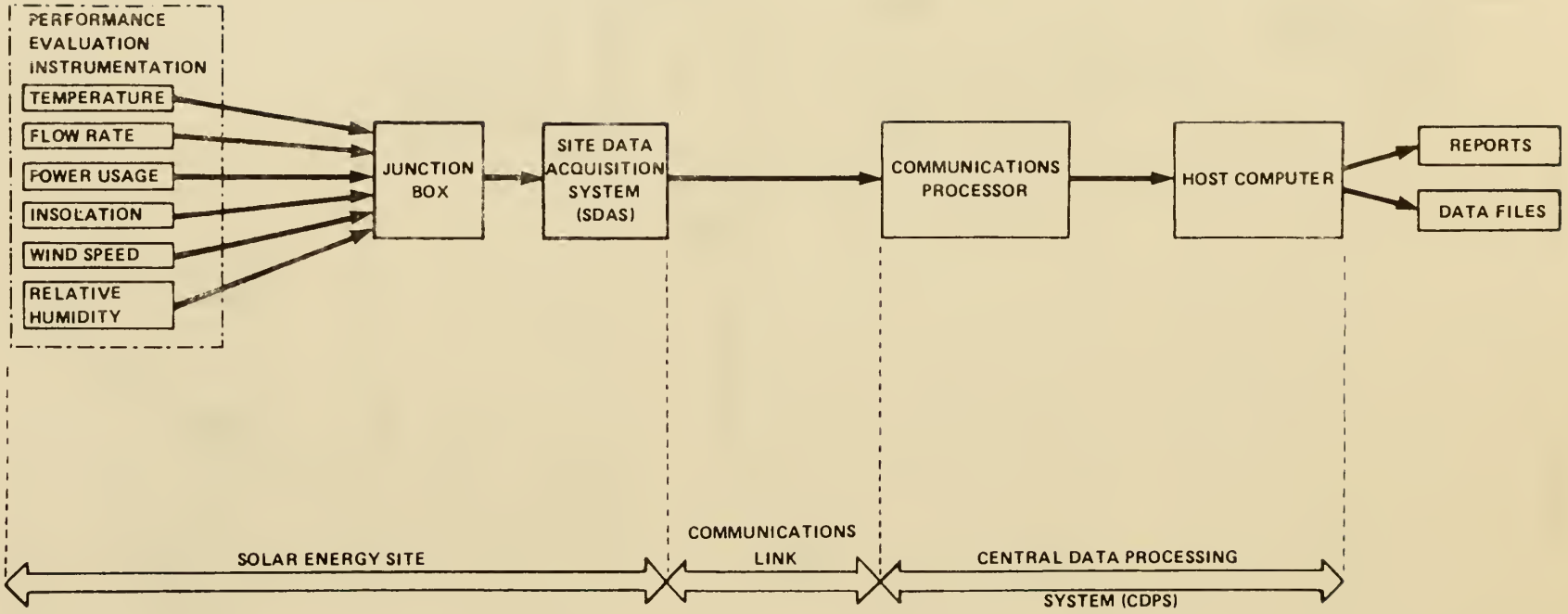


Figure V-A-2. Data Flow Path for the National Solar Data Network

The Communications Processor scans the receiving data to identify any apparent transmission errors and verifies correct site contact by checking the address code transmitted by the SDAS. Data is stored temporarily in the Communications Processor and processed by the Host Computer. The processing includes measurement checking to ensure that the data are reasonable; that is, that they are not beyond the known instrument limits and that they are not erratic. Data which appear questionable are discarded and are not used in the solar system preformance analyses.

Appropriate equations were formulated and programmed to define desired performance factors for the solar energy systems at each selected demonstration site. A performance factor is a number that describes either the efficiency or the quantity of energy lost, gained, or converted by a solar energy system or by a component. All vaid data are processed using these performance factor equations to generate hourly performance factors. Hourly performance factors are integrated into daily and monthly performance factors. These hourly, daily, and monthly performance factors are stored in data files in the CDPS. These data files also include measurement data, expressed in engineering units; numerical and textual site identification; and specific site data used in generating the performance factors.

B. On-Site Instrumentation

The on-site instrumentation includes sensors to monitor the various parameters of the solar energy system, a junction box, and a Site Data Acquisition System that stores and transmits data to the Host Computer (see figure V-A-1 and V-A-2). Specific information for temperature, flow, power and miscellaneous sensors are presented in tabular form. Sensor locations are shown in figure V-B-1.

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
I001	Insolation, total	Eppley PSP
T001	Temperature, ambient	S53P-60
T100	Temperature, collector inlet	S57P-60
T150	Temperature, collector, high	S53P-60
W100	Flow, collector	MKV-1¼, 3-30 GPM
EP100	Power,collector pump	PC5-1
T101	Temperature, heat exch. out	S57P-60
T151	Temperature, heat exch. in	S53P-60
T200	Temperature, storage tank, upper	S53P-156
T201	Temperature, storage tank, middle	S53P-346
T202	Temperature, storage tank, lower	S53P-556
T203	Temperature, storage tank outer surface	S32B
T204	Temperature, storage tank out	S57P-60
T254	Temperature, storage tank in	S53P-60
W200	Flow, storage/HX loop	MKV-1¼, 3-30 GPM
T400	Temperature, water coil inlet	S57P-60
T450	Temperature, water coil low	S53P-60
W400	Flow, water coil	MKV-1, 1-10 GPM
EP200	Power, heat exch. pump	PC5-1
T300	Temperature, return from heat exch.	S53P-60
T301	Temperature, supply to DHW heat exch	S57P-60
T351	Temperature, DHW heat exch. low	S53P-60
W300	Flow, DHW heat exch	MKV 3/4, 7-7 GPM
EP300	Power, DHW heat exch. pump	PC5-1
T302	Temperature, cold water supply	S57P-60
T352	Temperature, DHW tank, high	S53P-60
W301	Flow totalizer, DHW supply	Hersey 430
EP301	Power, DHW heater	PC5-29
T303	Temperature, DHW tank, outer surface	S32B
T401	Temperature, return air	S57P-100
T402	Temperature, heat pump coil, high	S57P-100
T403	Temperature, electric heater, high	S57P-100
T404	Temperature, water coil, high	S53P-100
W401	Flow, heated space	Kurz 430DC

SENSOR	DESCRIPTION OF MEASUREMENT	MODEL NO.
W402	Flow, heated space	Kurz 430DC
EP400	Power, indoor heat pump fan	PC-2
EP401	Power, electric heat strip	PC5-32
EP402	Power, heat pump, outdoorunit	PC5-29
T600	Temperature, building	S53P-100

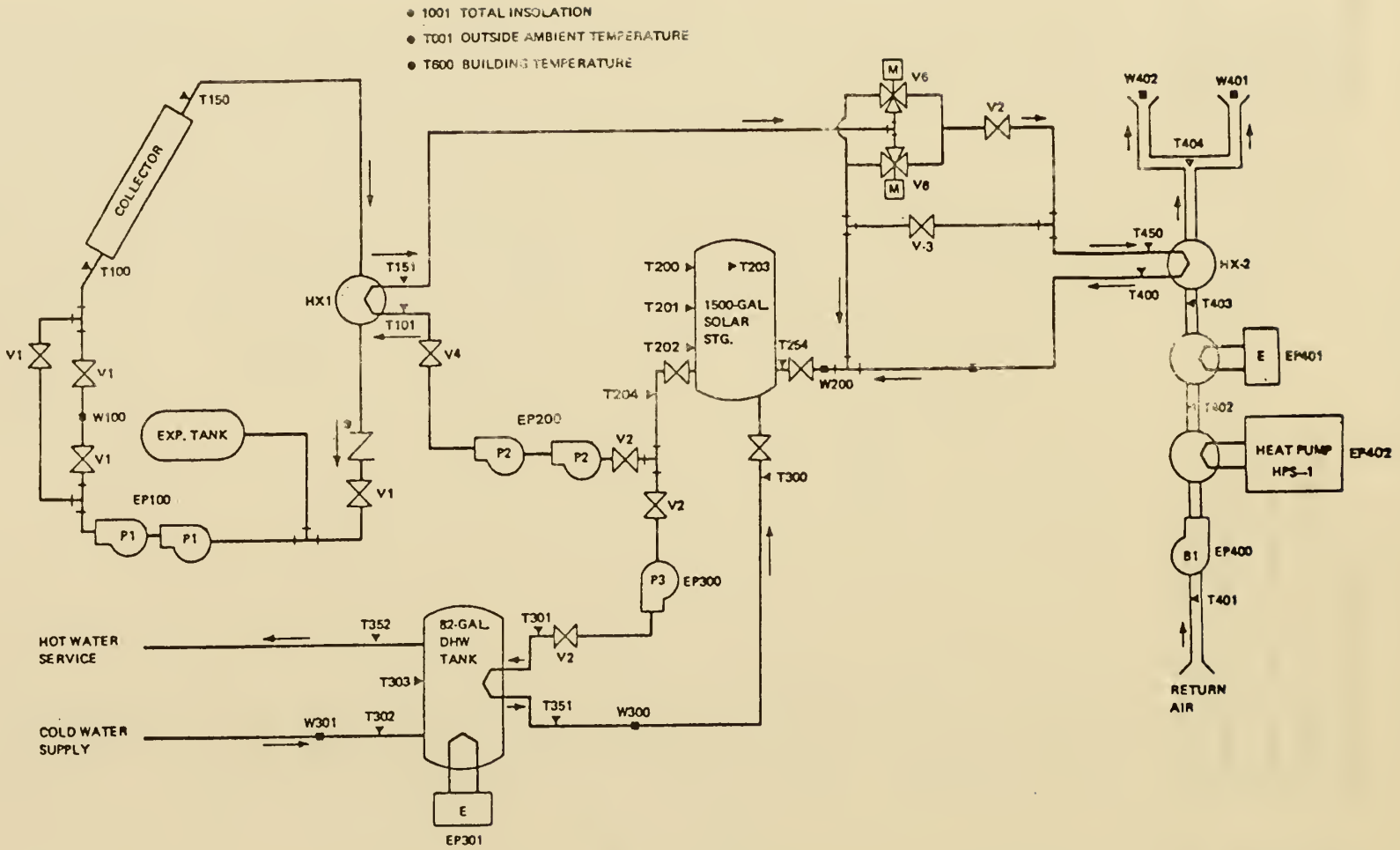


Figure V-B-1. Sensor and Control Diagram

VI. COST DATA

A. General

The following cost data depicts only solar energy portion of the construction costs. Costs of instrumentation is not included since it is not part of the construction effort.

B. Construction Grant Funds

Solar Subsystem	Applicants Request	Construction Grant
Collectors	$ 4,609	$
Energy Storage	1,600	
Distribution and Controls	9,077	
Installation	13,650	
Other	7,689	1,064
Total	$36,625	$26,000

C. Construction Period: February, 1977 through February, 1978

VII. APPENDIX

A. Glossary

ABSORBER PLATE - The surface in a flat plate collector that absorbs incident solar radiation and transfers the absorbed energy to a heat transfer fluid.
ABSORPTANCE - The ratio of absorbed radiation by a surface to the total incident radiation on that surface.
ABSORPTION SUBSYSTEM - The mechanical equipment that conditions indoor air by an absorption process.
ACTIVE SOLAR SYSTEM - An integrated solar energy system, consisting of collector, storage, solar energy-to-load subsystems, that can condition indoor air or preheat domestic hot water in a controlled manner.
AIR-BASED SOLAR COLLECTOR SYSTEM - A solar energy system in which air is the heat transfer fluid.
AIR CONDITIONING - The process of treating indoor air by controlling the temperature, humidity, and distribution to specified comfort settings as set by the occupants in the conditioned space.
AMBIENT AIR - A term for outdoor air, and may be brought into a building to be conditioned or circulated.
ANTI-FREEZE FREEZE PROTECTION SYSTEM - A freeze protection system that uses additives or solutions to the heat transfer medium, which depresses its freezing point sufficiently to prevent possible water freeze in the solar collectors and the exterior piping.
AUXILIARY ENERGY SUBSYSTEM - The equipment, utilizing conventional energy sources, used to supplement the output provided by a solar energy system and used to provide a full backup system when the solar system is inoperable.
BACKFLOW - The reversal of flow in a distribution system.
BACKFLOW PREVENTOR - A device or means to stop backflow.
BEAM RADIATION - Solar radiation which is not scattered and may be concentrated.
BRITISH THERMAL UNIT (Btu) - A unit of energy that is required to heat one pound of water from 59^{o} F to 60^{o} F.
BUILDING ENVELOPE - The exterior surface of a building that encloses the conditioned space.

CLIMATE - The prevailing or average weather conditions of a specific geographic region as described by temperature and other meteorological data.

COLLECTOR MANIFOLD - The piping that connects the absorber tubes in a collector plate.

COLLECTOR PLATE - A term used for an absorber plate.

COLLECTOR SUBSYSTEM - The assembly that absorbes solar radiation and transfers the absorbed thermal energy to a heat transfer fluid.

COMBINED COLLECTORS - An assembly that both collects solar radiation and stores the thermal energy in the same unit.

CONCENTRATING SOLAR COLLECTOR - A solar collector which focuses beam radiation onto an absorber in order to obtain higher energy fluxes than can normally be achieved by flat plate solar collectors.

CONCENTRATOR - A reflective surface or refracting lens used in directing insolation onto an absorber.

CONDITIONED SPACE - The space in a building where the air is conditioned by heating or cooling.

CONTROL SUBSYSTEM - The assembly of electric, pneumatic, and hydraulic actuated sensing devices used in regulating the solar energy system and the auxiliary energy subsystems.

COOLING TOWER - A heat exchanger that transfers waste heat from an absorption cooling system to ambient air.

DIFFUSE RADIATION - Solar radiation which is scattered by air molecules, dust, or other substances suspended in the air.

DRAIN-DOWN FREEZE PROTECTION SYSTEM - A freeze protection system that prevents potential water freeze-up within the collector and exterior piping by automatically draining and replacing the water with a non-freezing medium such as air, nitrogen, etc.

DUCT HEATING COIL - A liquid-to-air heat exchanger in the duct distribution system used to heat air by passing a hot fluid through a coil in the air system.

EQUIVALENT FULL LOAD COOLING HOURS - The seasonal cooling load for a building described as the total number of hours that the air conditioning system will operate under full load conditions to meet the required cooling load.

EMITTANCE - The ratio of energy radiated by a body to the energy radiated by a black body at the same temperature.

EXPANSION TANK - A tank which will permit water to expand whenever it is heated to prevent excessive pressures on the other system components.

FIXED COLLECTOR - A solar collector that is permanently oriented towards the sun and cannot track the sun nor be adjusted for seasonal variations.

FLAT PLATE COLLECTOR - A basic heat collection device used in solar heating systems, which consists of an absorber plate, with insulated bottom and sides, and covered by one or more transparent covers. There are no concentrators or focusing aids in a flat plate collector.

FOCUSING COLLECTOR - A solar collector using a parabolic mirror, fresnel lens, or other type of focusing device to concentrate solar radiation onto an absorber.

FRESNEL COLLECTOR - A concentrating solar collector which uses a fresnel lens to focus beam radiation onto an absorber.

GLAZING - The transparent cover(s) on a solar collector used to reduce the energy losses from the top of the collector.

HEAT TRANSFER FLUID - The fluid that transfers solar energy from the solar collector to the storage subsystem or to the load.

INCIDENCE ANGLE - The angle in which the insolation strikes a surface and the normal for that surface.

INSOLATION - The total amount of solar radiation on a surface in a given unit of time.

LAMINATED GLASS - A glazing consisting of multiple glass sheets bonded together by intervening layer or layers of plastic.

LANGLEY - The standard unit of insolation defined as 1 langley = 1 cal/cm^2, (1 Langley = 3.69 Btu/ft^2).

LIQUID-BASED SOLAR COLLECTOR SYSTEM - A solar energy system in which either water or an antifreeze solution is the heat transfer fluid.

LOAD - The total space conditioning or domestic water heating requirements that are supplied by both the solar energy system and the auxiliary energy subsystem.

NOCTURNAL RADIATION - The loss of thermal energy by the solar collectors to the sky at night.

NO-FLOW CONDITION - The condition obtained when the heat transfer fluid is not flowing through the collector array due to a shutdown or a malfunction.

OPAQUE - A surface that is not transparent, thus solar radiation is either reflected or absorbed.

OUTGASSING - The emission of gases by materials and components, usually during exposure to elevated temperature, or reduced pressure.

PACKAGE AIR-CONDITIONING UNIT - A factory-made assembly consisting of an indoor coil, a compressor, an outdoor coil, and other components needed for space cooling operations. This unit may also include additional components to heat the condition space.

PARABOLIC FOCUSING COLLECTOR - A concentrating collector which focuses beam radiation by a parabolic reflector.

PASSIVE SOLAR SYSTEM - An integrated solar energy system that can provide for space heating needs without the use of any other energy source other than the sun.

REFLECTANCE - The ratio of radiation reflected by a surface to the total incident radiation on the surface.

REFLECTED RADIATION - Insolation which is reflected from a surface, such as the ground, and is incident on the solar collector.

ROCK BED - A storage tank using uniform-sized rocks to store solar energy in air-based solar collector systems.

SELECTIVE SURFACE - A surface which has a high absorptance for solar radiation and a low emittance for thermal radiation.

SOLAR CONDITIONED SPACE - The area in a building that depends on solar energy to provide for a fraction of the heating and cooling needs.

SOLAR HEATING SYSTEM - An integrated assembly of collector, storage, solar energy-to-load, and control subsystems required to convert solar energy into thermal energy for space heating requirements, as well as the addition of an auxiliary backup system.

SOLAR RETROFIT - The addition of a solar energy system to an existing structure.

STORAGE SUBSYSTEM - The components used to store solar energy so that the stored energy can be used for heating, cooling, or heating water during periods of low insolation.

STRATIFICATION - The horizontal layering in a medium due to temperature differentials, commonly noticed in storage tanks filled with water.

THERMOSTAT - A temperature sensing device which controls the heating and cooling systems for space conditioning or the hot water heater.

TILT ANGLE FROM HORIZONTAL - Angle between the horizontal plane and the plane of collector.

TON OF REFRIGERATION - A unit of refrigeration which is equivalent to 12,000 Btu/hr.

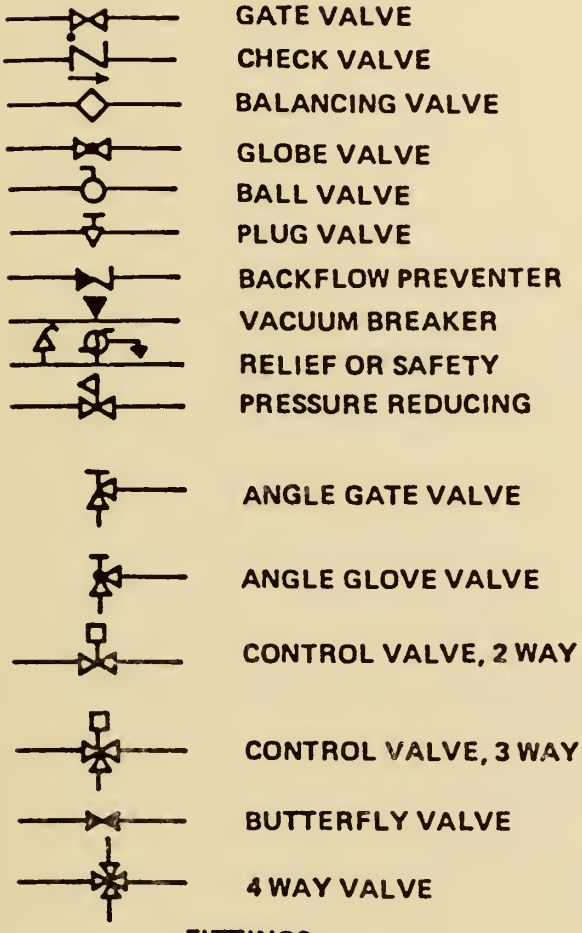
TRACKING COLLECTOR - A set of solar energy tracking collectors that automatically move in order to constantly aim towards the sun.

VAPOR BARRIER - A material which is used to reduce the transmission of water vapor.

ZONE - A portion of a conditioned space which use a common control because of their similar heating and cooling requirements.

B. Legend For Solar System Schematics

VALVES



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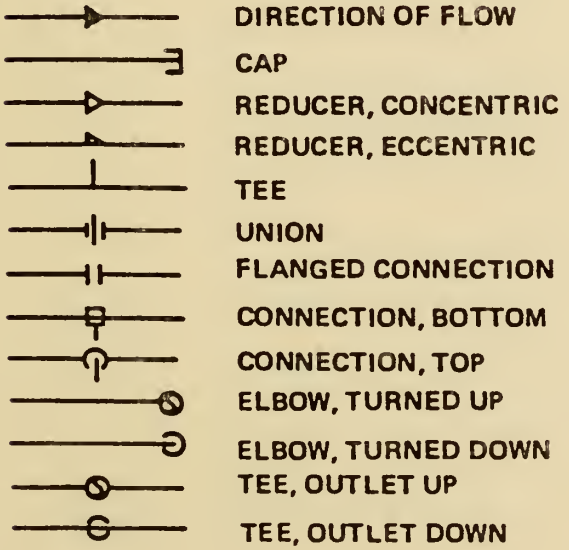

PIPING SPECIALITIES